sufficiently marked to have enabled chemists to differentiate it from associated elements.

III. "Molecular Magnetism." By Professor D. E. Hughes, F.R.S. Received May 10, 1881.

During the course of some late researches, which I had the honour to communicate to the Royal Society, March 7th,* and experimentally illustrate on the reading of my second paper, March 31,† many experimental facts occurred, all pointing to the conclusion that ordinary molar magnetism is entirely due to the symmetrical arrangement of the polarised molecules, and that these molecules can be rotated by torsion, so as to decrease the longitudinal magnetism, or increase it, if the effect of the elastic torsion is to rotate the molecules into the required longitudinal symmetrical arrangement. And observing that molecular magnetism could induce an electric current upon its own molar constituents, or that an electric current by its passage through an iron wire would produce molecular magnetism, I have continued these researches in the hope of elucidating, as far as possible, the phenomenon of the transformation of electricity and magnetism by the changes produced in the molecular structure of its conducting wire.

For this purpose I have employed three separate methods of investigation, each requiring a slightly modified form of apparatus. The first relates to the influence of an elastic torsion upon a magnetic or conducting wire; the second, to the influence upon the molecular structure of an iron wire of electricity or magnetism; the third, to the evident movement of the molecules themselves as given out in sonorous vibrations.

The general details of the apparatus employed having been given in my paper of March 7th, I will only briefly indicate any modification of the method employed.

1. *Influence of an Elastic Torsion upon a Magnetic or an Electric Conducting Wire.*

In my paper of March 7th on "Molecular Electro-Magnetic Induction," I showed that induced currents of electricity would be induced in an iron wire placed on the axis of a coil through which intermittent currents were passing, and that these currents were produced only when the wire was under the influence of a torsion not passing its limit of elasticity. It became evident that if the intermittent magnetism induced by the coil produced under torsion intermittent currents

* "Molecular Electro-Magnetic Induction," "Proc. Roy. Soc.," vol. 31, p. 525.

† "Permanent Molecular Torsion of Conducting Wires produced by the Passage of an Electric Current," *Ibid.*, vol, 32, p. 25.

of electricity, an intermittent torsion under the influence of a constant current of electricity or a constant magnetic field would produce similar currents. This was found to be the case, and as some new phenomena presented themselves indicating clearly the molecular nature of the actions, I will describe a few of them directly relating to the subject of this paper.

The apparatus used was similar to that described in my paper of March 7th. An iron wire of 20 centims. was placed in the centre or axis of a coil of silk-covered copper wire, the exterior diameter of the coil being $5\frac{1}{2}$ centims., and that of the interior vacant circular space $3\frac{1}{2}$ centims. The iron wire is fastened to a support at one end, the other passing through a guide, to keep it parallel to the axis but free, so that any required torsion may be given to the wire by means of a connecting arm or index. A sensitive telephone is in direct communication with the coil, or a galvanometer may be used, as the currents obtained by a slow elastic torsion are slow and strong enough to be seen on a very ordinary galvanometer. I prefer, however, the telephone, because it has the inestimable advantage in these experiments of giving the exact time of the commencement or end of an electric current. It has, however, the disadvantage of not indicating the force or direction of the current; but by means of the sonometer the true value and direction of any current is at once given. Again, the telephone is useless for currents of slow intermittence; but, by joining to it the microphonic rheostat described in my paper of March 7th, a slowly intermittent or permanent current is broken up into rapidly intermittent currents, and then we are able to perceive feeble constant currents. For this reason a microphonic rheostat is joined to the telephone and coil. The current from a battery of two bichromate cells is sent constantly through the wire if we wish to observe the influence of the torsion of the wire upon the electric current, or a constant field of magnetic energy is given to the wire by either a separate coil or a permanent magnet. The currents obtained in the coil are induced from the change in the molecular magnetism of the wire, but we may equally obtain these currents in the wire itself without any coil by joining the telephone and rheotome direct to the wire; in the latter case, it is preferable to join the wire to the primary of a small induction coil, and the telephone and rheotome to the secondary, as then the rheotome does not interrupt the constant electric current passing through the wire. As the results are identical, I prefer to place the telephone on the coil first named, as the tones are louder and entirely free from errors of experimentation.

If we place a copper wire in the axis of the coil we produce no effect by torsion, either when under the influence of a constant magnetic field or a current passing through it, nor do we perceive any effects if we place an iron wire (2 millims. in diameter), entirely free

from magnetism and through which an electric current has never passed. I mention this negative experiment in order to prove that all the effects I shall mention are obtained only through the magnetism of the wire. If now I pass an electric current for an instant through this same wire, its molecules are instantly polarised. I have never yet been able to restore the wire to its original condition, and the magnetisation induced by the passage of a current is far more powerful and more persistent in soft iron than tempered steel. This may be due, however, to the fact that in tempered or softened steel we find traces only of a current during to the rotation by torsion of its molecules, some two to three degrees of sonometer, whilst iron gives constantly a current of 70 sonometric degrees.*

In order to obtain these currents, we must give a slight torsion of 5° or 10° to and fro through the zero point. We then have a current during the motion of the index to the right, and a contrary current in moving the index to the left. If we use a galvanometer, we must time these movements with the oscillations of the needle; but with the telephone it gives out continuous sounds for either movement, the interruptions being only those caused by the rheotome. The direction of the current has no influence on the result; either positive to the free arm or index or negative gives equal sounds, but at the moment of reversal of the current a peculiar loud click is heard, due to the rapid change or rotation of the polarisation of its molecules, and this peculiarly loud momentary click is heard equally as well in steel as in iron, proving that it is equally polarised by the current, but that its molecular rigidity prevents rotation by torsion. We can imitate in some degree the rigidity of steel by giving the iron wire several permanent twists. The current due to elastic torsion is then reduced from 70° to 40°, in consequence of the mechanical strain of the twists remaining a constant; and a weakening of the current is also remarked if with a fresh wire we pass in torsion its limit of elasticity.

If a new soft iron wire of 2 millims. (giving no traces of a current by torsion) has passed through it a momentary current of electricity, and the wire is then observed free from the current itself, it will be found to be almost as strongly polarised as when the current was constantly on, giving by torsion a constant of 50 sonometric degrees. If, instead of passing a current through this new wire, I magnetise it strongly by a permanent magnet or coil, the longitudinal magnetism gives also 70° of current for the first torsion, but weakens rapidly, so that in a few contrary torsions only traces of a current remain, and we find also its longitudinal magnetism almost entirely dissipated. Thus there is this remarkable difference, that, whilst it is almost impossible to free the wire from the influence produced by a current, the longitudinal magnetism yields at once to a few torsions. We may, however, trans-

* 0·8 of a Daniell battery.

form the ring or transversal magnetism into longitudinal magnetism by strongly magnetising the wire after a current has passed through it. This has the effect of rotating the whole of the molecules, and they are all now symmetrical with longitudinal magnetism; then, by a few torsions, the wire is almost as free as a new wire. I have found this method more efficacious than heating the wire red hot, or any other method yet tried. If I desire a constant current from longitudinal magnetism, I place at one of the extremities of the wire a large permanent magnet, whose sustaining power is 5 kilogrammes, and this keeps the wire constantly charged, resembling in some respects the effects of a constant current. The molecular magnetism or the current obtained by torsion is not so powerful from this, my strongest magnet, as that produced by the simple passage of a current, being only 50 sonometric degrees in place of 70° for that due to the passage of a current. The mere twisting of a longitudinal magnet, without regard to the rotation of its molecules has no effect, as is proved by giving torsion to a steel wire strongly magnetised, when only traces of a current will be seen, perhaps one or two degrees, and by using a constant source of magnetism or electricity, when no measurable effect will be obtained. Evidently we have as much twisted the magnetised steel as the soft iron. In the steel we have a powerful magnet, in the soft iron a very feeble one; still the molecular rotation in iron produces powerful currents to the almost absolute zero of tempered steel.*

If we magnetise the wire whilst the current is passing, and keep the wire constantly charged with both magnetism and electricity, the currents are at once diminished from 70° to 30°. We have here two distinct magnetic polarisations at right angles to each other, and no matter what pole of the magnet, or of the current, the effect is greatly diminished; the rotation of the two polarities would now require a far greater arc than previously. The importance of this experiment cannot as yet be appreciated until we learn the great molecular change which has really occurred, and which we observe here by simply diminished effects.

If we heat the wire with a spirit flame, we find the sounds increase rapidly from 70 to 90, being the maximum slightly below red heat. I have already remarked in my previous paper this increased molecular activity due to heat, and its effects will be more clearly demonstrated when we deal with the sounds produced by intermittent currents.

Another method, by means of which I have again received proofs of the rotation of the polarised molecules, is to pass an intermittent current through a soft 0·5 millim. iron wire, listening to the results by the telephone joined direct and alone to the coil, as described in

* I purposely avoid using the terms "magnetic fluid" and "coercitive force."

my paper of March 7. If the wire is then entirely free from strain, we have silence, but a torsion of 20° produces some 50 sonometric degrees of electric force. If, now (the wire being at zero strain), I bring one pole of the permanent magnet I have already described near the side of the wire, the sounds increase from zero up to 50°, being at their maximum when this magnet is 5 centims. distant; but if we continue to approach the magnet the sounds gradually weaken almost to zero. The explanation of this fact can be found when we know that the greatest inductive effect on the wire would be when a magnet is at an angle of 45° with the wire. And, also, considering each molecule as a separate independent magnet, we find that at a given distance for a given magnet the force of rotation is equal to that of 45°; by approaching the magnet we increase the rotation but diminish the angular polarity in relation to the wire, hence the decrease of force by the near approach of the magnet. And to prove that the function of the elastic torsion is simply to rotate the polarised molecules similarly to the magnet, we place the wire under an elastic torsion of 20°, and approach gradually the magnet as before. One pole now will be found to increase the sounds or its angular polarity, the other will diminish them, until at 5 centims. distance, as before, we have perfect silence; the torsion exists as before, but the molecules are no longer at the same angle. On removing the magnet we find that instead of the usual 50 of current we obtain barely 5 or 10: have we then destroyed the polarity of the molecules, or do they find a certain resistance to their free rotation to their usual place? To solve this question we have only to shake the wire, or give it a slight mechanical vibration, and then instantly the molecules rotate more freely, and we at once find our original current of 50°. I will forbear mentioning many other experimental proofs of my views by this method, as there are many to relate by different methods in the following sections.

2. *Influence upon the Molecular Structure of an Iron or Steel Wire of Electricity or Magnetism.*

Being desirous to modify the apparatus already described, so that it should only give indications of a current if it were of a spiral nature, the wire was kept rigidly at its zero of strain or torsion, and the coil was made so that it could revolve on an axis perpendicular to the wire; by this means, if the wire was free from strain, the centre or axis of the coil would coincide with that of the wire. Thus, with a straight copper wire, we should have a complete zero, but if this wire formed a right or left-handed helix, the coil would require moving through a given degree (on an arbitrary scale) corresponding to the diameter and closeness of the spirals in the helix; the degrees through which the coil moved, were calibrated in reference to known

copper helices. 50° equalled a copper wire 1 millim. diameter, formed into a helix of 1 centim. diameter, whose spiral turns were separated 1 centim. apart.

In order to obtain a perfect zero, and wide readings, with small angular movement of the coil, it is necessary that the return wire should be of copper, 2 millims. diameter, offering comparatively little resistance, and that it should be perfectly parallel with the steel or iron wire. In order that it may react upon the exterior of the coil, it is fastened to the board, so that it is near (1 centim.) the exterior of the coil, and parallel to the iron wire, at a distance of 4 centims. If we consider this return wire alone, we find, as in the sonometer, that if the wire is perpendicular to the exterior wires of the coil, we have a zero or silence, but moved through any degree, we have a current proportionable to that degree; by this means, we have an independent constant acting on the coil, constantly aiding the coil in finding its true zero, and allowing of very wide readings, with a comparatively small angular movement of the coil.

The rheotome is joined to a battery of two bichromate cells, and by means of a reversing switch, an intermittent current of either direction can be sent through the wire. The telephone is joined direct and alone to the coil; thus no currents react upon the coil when perpendicular to the iron, and its return wire, if not of a spiral nature.

Placing an iron wire 0·5 diameter, and passing a current through it, I found a change had taken place similar to those indicated in my paper of March 17th; but it was so difficult to keep the wire free from magnetism and slight molecular strains, that I preferred and used only in the following experiments tempered steel wire (knitting needles I found most useful). All the effects are greatly augmented by the use of iron wire, but its molecular elasticity is so great that we cannot preserve the same zero of reading for a few seconds together, whilst with steel, 0·5 millim. diameter, the effects remained constant until we removed the cause.

I have not as yet been able to obtain a steel wire entirely free from magnetism, and as magnetism in steel has a remarkable power over the direction of the spiral currents, I will first consider those in which I found only traces. On passing the intermittent current through these, the sounds were excessively feeble for either polarity of current, but, at each reversal, a single loud click could be heard, showing the instant reversal of the molecular polarity. The degree of coil indicating the twist or spirality of the current was 5° on each side of its true zero. The wire was now carefully magnetised, giving 10° on each side for different currents. The positive entering at north pole indicating 10° right-handed spiral, the negative entering the same pole, a left-handed spiral, we here see in another form, a fact well known and demonstrated by De la Rive by a different method, that an electric current

travels in spirals around a longitudinal magnet, and that the direction of this spiral is entirely due to which pole of an electric current enters the north or south pole. I propose soon, however, to show that under certain conditions these effects are entirely reversed.

If through this magnetised wire I pass a constant current of two bichromate cells, and at the same time an intermittent one, the spiral is increased to 15°, but the direction of the intermittent current entirely depends on that of the constant current. Thus, if the positive of the constant current enters the north pole, the intermittent positive slightly increases the spiral to 17°, and the negative to 13°, both being right-handed; the two zeros of the constant battery are, however, as we might expect from the preceding experiment, on opposite sides of and at equal distances from the true zero; but if we magnetise the wire whilst a constant current is passing through it, a very great molecular disturbance takes place; loud sounds are heard in the telephone, and it requires for each current a movement of the coil of 40°, or a total for the two currents of 80°. This, however, is not the only change that has taken place, as we now find that both constant currents have a right-handed spiral; the positive under which it was magnetised, a right-handed spiral of 95°; the negative, a right-handed spiral of 15°, and the true central or zero point of the true currents indicates a permanent spiral of 55°.

This wire was magnetised in the usual way, by drawing the north pole of my magnet from the centre to one extremity, the south from the centre to the other, and this was repeated until its maximum effects were obtained. In this state I fouud, sliding the coil at different portions, that the spiral currents were equal, and in the same direction throughout.

It now occurred to me to try the effect of using a single pole of the magnet; this was done whilst a constant current was passing through the wire, commencing at the extremity where the positive joined, drawing the north pole through the length of the wire, from positive towards the negative; the effect was most remarkable, as the steel wire now gave out as loud tones as a piece of iron, and the degree on the coil showed 200°. The constant and intermittent currents now showed for either polarity a remarkably strong right-handed twist; the positive 200 right, and the negative 150 right-handed spirals. The molecular strain on the wire from the reaction of the electric current upon the molecular magnetism was so great, that no perfect zero would be obtained at any point, a fact already observed when a wire was under an intense strain, producing tertiary currents that superposed themselves upon the secondary. In order to compare these spiral currents with those obtained from a known helix, I found that taking a copper wire of similar diameter (0·5 millim.), and winding it closely upon the steel wire ten turns to each centimetre,

having a total of 200 turns, with an exterior diameter of 1·5 millims., withdrawing the steel wire, leaving this closely wound helix free, it gave some 190°, instead of the 200 of the steel wire alone; thus the spiral currents fully equalled a closely wound copper wire helix of 200 turns in a similar length.

If it were possible to twist a magnetised wire several turns to the right, and that its line of magnetism should coincide with that of the twist, then on passing a positive or negative current, there would be an apparent augmented or diminished spirality of the current, but both would have a right-handed twist. The result would be identical with the phenomenon described, although the cause is different.

The explanation of this phenomenon can be probably found in the fact that the constant spirality now observed is that of the electric current under which it was magnetised, for whilst magnetising it we had a powerful source of magnetism constantly reacting upon the electric current, and the constant spirality now observed is the result or remains of a violent molecular reaction at the instant of magnetisation, and the remaining evident path or spiral is that of the electric current. On testing this wire as to its longitudinal magnetic force, I found that it was less than that of a wire simply magnetised in the usual way; thus the effects are internal, affecting the passage of the electric current, giving, however, no external indications (except apparent weakness) of the enormous disturbance which has taken place.

If, instead of drawing the north pole of the magnet as above, from positive towards negative, I draw it from negative to positive, all the effects are repeated, except that we have now, as we should expect, a left-handed spiral. But if I draw the magnet from the extremities of the wire to the centre, then at this centre I find an absolute zero of twist, but on each side a contrary twist, the wire then having a left and right-handed twist, the positive travelling towards the centre in a right-handed twist gradually ceasing in zero; this is as we might expect, but if done under the influence of a constant current, no matter what pole of the battery enters afterwards the north pole of the magnet, it will have during its first half a right-handed, and its second a left-handed spiral. It became important to know if a wire which had been magnetised under the influence of a current could be restored to something like its original condition. Electric currents had no effect. Heat, which would not destroy its temper, had no effect. Mechanical vibrations and torsions failed to disturb the molecular arrangement; but magnetising it strongly by a magnet, when no current was passing, at once brought the wire to its usual apparently rigid state, and the constant or intermittent currents now indicated only 18° of spiral currents against a previous 200°, and the sounds were, as usual from steel, excessively weak. I have since used this method with invariable success, when I wished to repeat

the experiments upon the same wire. If these experiments are repeated upon an iron wire, the effects are far greater in the first instance, so great that they were thrown out of the range of my measurements; it was only after a few seconds of successive reversals that the zero of the wire was brought within range, and although these rapidly decreased, exactly similar effects were observed as in the steel. And as with all moderate ranges, I could bring the iron at once to a complete zero by torsion, and as torsion alone would produce this complete zero, I believe we have here effects from causes identical with those related in the first chapter.

Having noticed in my previous papers the increased molecular activity caused by the approach of a powerful permanent magnet, and believing that the permanent spirality above mentioned was due to this alone, and not to an increased polarity, I magnetised strongly an iron wire giving as usual a reversed spiral for different currents of but 10°. I now heated the wire by a spirit flame to a dull red heat, whilst the current was passing through it, and on cooling I found a similar but stronger permanent torsion of 250°; both currents, as in the previous experiments, having a right-handed spiral. Thus a current of electricity passing through a wire nearly red hot determines a molecular arrangement, or path, which on cooling forces currents of either direction to follow the path which had been determined under the influence of heat.

3. *Molecular Sounds.*

The passage of an intermittent current though iron or other wire gives rise to sounds of a very peculiar and characteristic nature. Page, in 1837, first noticed these sounds on the magnetisation of wires in a coil. De la Rive published a chapter in his "Treatise on Electricity" (1853) on this subject, and he proved that not only were sounds produced by the magnetisation of an iron wire in an inducing coil, but that sounds were equally obtained by the passage direct of the current through the wire. Gassiot, 1844, and Du Moncel, 1878–81, have both maintained the molecular character of these sounds. Reis made use of them in his, the first electric telephone invented, and these sounds, since the apparition of Bell's telephone, have been often brought forward as embodying a new form of telephone. These sounds, however, for a feeble source of electricity, are far too weak for any applied purposes, but they are most useful and interesting where we wish to observe the molecular action which takes place in a conducting wire. I have thus made use of these sounds as an independent method of research, and by their means verify any point left doubtful by other methods, some of which I have already described.

The apparatus was the same as that described in the last section,

except that no telephone was used. By means of a switch key the intermittent electric current was either connected with the coil inducing longitudinal magnetism in the wire, or could be thrown instantly through the wire itself, thus rapid observations could be made of any difference of tone or force by these two methods ; a reversing key also allowed, when desired, a constant current of either polarity to pass through the wire under observation.

Of all metals that I have yet tried, iron gave by far the loudest tones, though by means of the microphone I have been able to hear them in all metals ; but iron requires no microphone to make its sounds audible, for I demonstrated at the reading of my paper, March 31st, that these sounds with two bichromate cells were clearly audible at a distance. A fine soft iron wire (No. 28) is best for loud sounds to be obtained by the direct passage of the current, but large wires (1 millim.) are required for equally loud tones from the inducing coil. By choosing any suitable wire between these sizes we can obtain equal sounds from the longitudinal magnetism or direct current. The wire requires to be well annealed, in fact, as in all preceding experiments, the sounds are fully doubled by heating the wire to nearly red heat. There are many interesting questions that these molecular sounds can aid in resolving, but as I wish to confine the experiments to the subject of the two preceding chapters, I will relate only a few which I believe bear on the subject.

On sending an intermittent electric current through a fine soft iron wire we hear a peculiar musical ring, the cadence of which is due to that of the rheotome, but whose musical note or pitch is independent both of the diameter of the wire and the note which would be given by a mechanical vibration of the wire itself. I have not yet found what relation the note bears to the diameter of the wire; in fact, I believe it has none, as the greatest variation in different sizes and different conditions has never exceeded one octave, all these tones being in our ordinary treble clef, or near 870 single vibrations per second, whilst the mechanical vibrations due to its length, diameter, and strain vary many octaves.

I believe the pitch of the tone depends entirely upon molecular strain, and I found a remarkable difference between the molecular strain caused by longitudinal magnetism and the transversal or ring magnetism produced by the passage of a current. For, if we pass the current through the coil, inducing magnetism in the wire, and then gradually increase the longitudinal mechanical strain by tightening the wire, the pitch of the note is raised some three or four tones (the note of the mechanical transversal vibrations being raised perhaps several octaves) ; but if we tighten the wire during the passage of an electric current through it, its pitch falls some two or three notes, and its highest notes are those obtained when the wire is quite loose. A

similar but reverse action takes place as regards torsion; for if the wire is magnetised by the coil we obtain an almost complete zero of sound by simply moving the torsion index 45° on either side, and as this was the degree which gave silence in the previous experiments for the same wire, it was no doubt due to the same rotation of its polarised molecules. If we now pass a constant current through the wire whilst the intermittent one is upon the coil, we hear augmented sounds, not in pitch but loudness; and if we give torsion of 45° to one side we have silence, or nearly so, whilst, to the other side, it gives increased tones which become silence by reversing the battery. If, whilst the wire by torsion has been brought to zero, we decrease or increase the mechanical longitudinal strain, then at once the polarised molecules are rotated, giving loud sounds; and we further remark that when the wire is loosened, and we again tighten it, we gradually approach a zero, and on increasing the strain the sounds return; thus we can rotate the molecules by a compound strain of torsion and longitudinal strain.

If we wish to notice the influence of a constant current passing through the wire under the influence of the intermittent current in the coil, we find, if the wire is free from torsion, that, on passing the current, the tones are diminished or increased according to the direction of the current. The tones then have an entirely distinctive character, for whilst preserving the same musical pitch as before, the tones are peculiar, metallic, and clear, similar to those given out when a glass is struck, whilst the tones due to longitudinal magnetism are dull and wanting in metallic timbre. If we now turn the index of torsion upon one side, we have a zero of sound with or without the current; but turning in the opposite direction gives increased tones whilst current is passing through the wire, but zero when not. Here again a peculiarity of timbre can be noticed, as although we have loud tones due only to the action of the current through the wire, the timbre is no longer metallic, but similar to that previously given out by the influence of the coil; evidently then the metallic ring could only be due to the angular polarisation of the molecules, and when these were rotated by torsion the tones were equally changed by its action upon the wire.

I have already shown that a permanent magnet brought near the wire can rotate its polarisation, and it equally can produce sound or silence (while the wire is at its zero of torsion, and a constant current is sent through the wire as in the last experiment): we find that either pole of the natural magnet has equal effect in slightly diminishing the sound by an equal but opposite rotation from the line of its maximum effects; but if the wire is brought nearly to zero by torsion, then on approaching one pole of the natural magnet we produce a complete silence, but the opposite pole at once rotates the molecules

in such a manner as to produce the maximum loudness, and on taking away the magnet we have comparatve silence as before.

Heating the wire to nearly red heat by a spirit lamp increases the tones of longitudinal magnetism induced by the coil some 25 per cent., but it effects a much more marked increase in the tones produced by the direct passage of the current, which are increased by more than 100 per cent.; and if we pass the intermittent current through the coil and constant through the wire, we find no direct rotation of the molecules by heat. Although an apparent rotation takes place if, by the required torsion, we first place the wire at its zero, for then on the application of heat faint sounds are heard, which become again almost silent on cooling, this is simply due to the diminution by heat of the effect of the elastic torsion.

Tempered steel gave exceedingly faint tones, requiring the use of the microphone; but on magnetising with a constant current, inducing spiral magnetism, the sounds became audible, some 15° sonometer against 175° for iron; thus the molecular rigidity of steel as observed by previous methods was fully verified.

I have mentioned only a few of the numerous experiments I have made by the three methods described, all of which, however, bear directly upon the molecular arrangement of electric conducting bodies. I have selected a few bearing directly upon the subject I have chosen for this paper.

I have, I believe, demonstrated by actual experiments which are easy to repeat, that—

1. An electric current polarises its conductor, and that its molecular magnetism can be reconverted into an electric current by simple torsion of its wire.

2. That it is by the rotation of its molecular polarity alone that an electric current is generated by torsion.

3. That the path of an electric current through an iron or steel wire is that of a spiral.

4. That the direction of this spiral depends on the polarity of the current, or that of its magnetism.

5. That a natural magnet can be produced, having its molecular arrangement of a spiral form, and consequently reversed electric currents would both have a similar spiral in passing through it.

6. That we can rotate the polarised molecules by torsion or a compound strain of longitudinal and transversal.

7. That the rotation or movements of the molecules give out clear audible sounds.

8. That these sounds can be increased or decreased to zero by means that alone have produced rotation.

9. That by three independent methods the same effects are produced, and that they are not due to a simple change or weakening of polarity,

as when rotation has been incomplete a mere mechanical vibration has at once restored the maximum effect.

10. That heat, magnetism, constant electric currents, mechanical strains and vibrations, have all some effect on the result.

III. "On the Identity of Spectral Lines of Different Elements." By G. D. Liveing, M.A., F.R.S., Professor of Chemistry, and J. Dewar, M.A., F.R.S., Jacksonian Professor, University of Cambridge. Received May 12, 1881.

The question of the identity of spectral lines exhibited by different elements is one of great interest, because it is very improbable that any single molecule should be capable of taking up all the immense variety of vibrations indicated by the complex spectrum of iron or that of titanium, and it might therefore be expected that such substances consist of heterogeneous molecules, and that some molecules of the same kind as occur in these metals should occur in more than one of the supposed elements. Further, the supposed identity of certain lines in the spectra of more than one element has been made by Mr. Lockyer the ground of an argument in support of a theory as to the dissociation of chemical elements into still simpler constituents, and in reference to this he wrote ("Proc. Roy. Soc." vol. 30, p. 31), "the 'basic' lines recorded by Thalén will require special study with a view to determine whether their existence in different spectra can be explained or not on the supposition that they represent the vibrations of forms, which, at an early stage of the planet's history, entered into combination with other forms, differing in proximate origin, to produce different 'elements.'"

Young, on examining with a spectroscope of high dispersion the 70 lines given in Ångström's map as common to two or more substances, has found that 56 are double or treble, 7 more doubtful, and only 7 appear definitely single ("American Journal of Science," vol. xx, 119, p. 353), and he remarks, "The complete investigation of the matter requires that the bright line spectra of the metals in question should be confronted with each other and with the solar spectrum under enormous dispersive power, in order that we may determine which of the components of each double line belongs to one and which to the other element." It is this confronting of the bright line spectra of some of the terrestrial elements which we have attempted, and of which we now give an account. For the dispersion we have used a reflecting grating similar to that used by Young, with 17,296 lines to the inch, and a ruled surface of about 3½ square inches; telescope and